

## CHAPTER 3

# PRINCIPLES OF FLIGHT

### INTRODUCTION

Man has always wanted to fly. Legends from the very earliest times bear witness to this wish. Perhaps the most famous of these legends is the Greek myth about a father and son who flew with wings made of wax and feathers. It was not, however, until the successful flight by the Wright brothers at Kitty Hawk, North Carolina, that the dream of flying became a reality. Since the flight at Kitty Hawk, aircraft designers have spent much time and effort in developing that first crude flying machine into the modern aircraft of today. To understand the principles of flight, you must first become familiar with the physical laws affecting aerodynamics.

### PHYSICAL LAWS AFFECTING AERODYNAMICS

**LEARNING OBJECTIVE:** Identify the physical laws of aerodynamics to include Newton's laws of motion and the Bernoulli principle.

Aerodynamics is the study of the forces that let an aircraft fly. You should carefully study the principles covered here. Whether your job is to fly the aircraft and/or to maintain it, you should know why and how an aircraft flies. Knowing why and how lets you carry out your duties more effectively.

### LAWS OF MOTION

Motion is the act or process of changing place or position. Simply put, motion is movement. An object may be **in motion in relation** to one object and **motionless in relation** to another. For example, a person sitting in an aircraft flying at 200 mph is at rest or motionless in relation to the aircraft. However, the person is in motion in relation to the air or the earth. Air has no force or power other than pressure when it's motionless. When air is moving, its force becomes apparent. A moving object in motionless air has a force exerted on it as a result of its own motion. It makes no difference in the effect whether an object is moving in relation to the air or the air is moving in relation to the object. The following information explains some basic laws of motion.

### Newton's First Law of Motion

According to Newton's first law of motion (inertia), an object at rest will remain at rest, or an object in motion will continue in motion at the same speed and in the same direction, until an outside force acts on it. For an aircraft to taxi or fly, a force must be applied to it. It would remain at rest without an outside force. Once the aircraft is moving, another force must act on it to bring it to a stop. It would continue in motion without an outside force. This willingness of an object to remain at rest or to continue in motion is referred to as *inertia*.

### Newton's Second Law of Motion

The second law of motion (force) states that if a object moving with uniform speed is acted upon by an external force, the change of motion (acceleration) will be directly proportional to the amount of force and inversely proportional to the mass of the object being moved. The motion will take place in the direction in which the force acts. Simply stated, this means that an object being pushed by 10 pounds of force will travel faster than it would if it were pushed by 5 pounds of force. A heavier object will accelerate more slowly than a lighter object when an equal force is applied.

### Newton's Third Law of Motion

The third law of motion (action and reaction) states that for every action (force) there is an equal and opposite reaction (force). This law can be demonstrated with a balloon. If you inflate a balloon with air and release it without securing the neck, as the air is expelled the balloon moves in the opposite direction of the air rushing out of it. Figure 3-1 shows this law of motion.

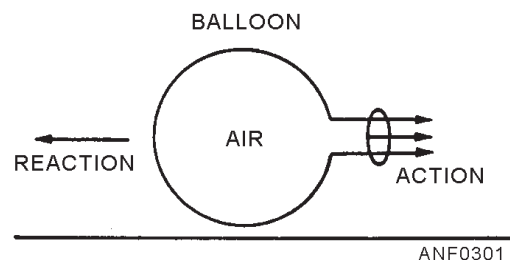


Figure 3-1.—Newton's third law of motion.

## BERNOULLI'S PRINCIPLE

Bernoulli's principle (fig. 3-2) states that when a fluid flowing through a tube reaches a constriction or narrowing of the tube, the speed of the fluid passing through the constriction is increased and its pressure is decreased.

- Q3-1. *The willingness of an object to stay at rest because of inertia is described by which of Newton's laws of motion?*
- Q3-2. *A heavy object will accelerate more slowly than a light object when an equal amount of force is applied. Which of Newton's laws describes this statement?*
- Q3-3. *If you blow up a balloon and then release it, it will move in what direction?*
- Q3-4. *When fluid reaches a narrow part of a tube, its speed increase and its pressure is decreased. What law does this statement describe?*

### THE AIRFOIL

**LEARNING OBJECTIVE:** Recognize the terms used to describe the various parts of an airfoil section and the terms used in explaining the airflow lift generation.

An airfoil is defined as that part of an aircraft that produces lift or any other desirable aerodynamic effect as it passes through the air. The wings and the propeller

blades of a fixed-wing aircraft and the rotor blades of a helicopter are examples of airfoils.

### AIRFOIL TERMINOLOGY

The shape of an airfoil and its relationship to the airstream are important. The following are common terms that you should understand before you learn about airfoils.

<i>Leading edge</i>	The front edge or surface of the airfoil (fig. 3-3).
<i>Trailing edge</i>	The rear edge or surface of the airfoil (fig. 3-3).
<i>Chord line</i>	An imaginary straight line from the leading edge to the trailing edge of an airfoil (fig. 3-3).
<i>Camber</i>	The curve or departure from a straight line (chord line) from the leading to the trailing edge of the airfoil (fig. 3-3).
<i>Relative wind</i>	The direction of the airstream in relation to the airfoil (fig. 3-4).
<i>Angle of attack</i>	The angle between the chord line and the relative wind (fig. 3-4).

### AIRFLOW AROUND AN AIRFOIL

The generation of lift by an airfoil depends on the airfoil's being able to create a special airflow in the airstream. This airflow develops the lifting pressure over the airfoil surface. The effect is shown in figure 3-5, which shows the relationship between lift and Bernoulli's principle. As the relative wind strikes the leading edge of the airfoil, the flow of air is split. A portion of the relative wind is deflected upward and aft, and the rest is deflected downward and aft. Since the

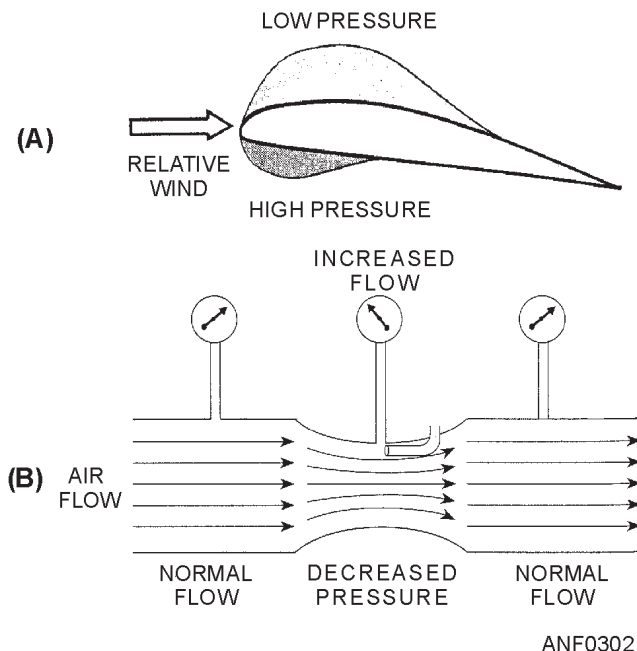


Figure 3-2.—Bernoulli's principle.

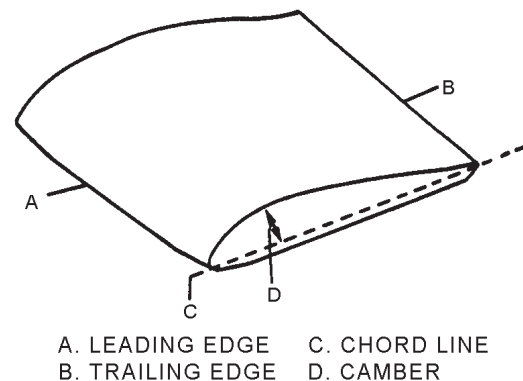


Figure 3-3.—Airfoil terminology.

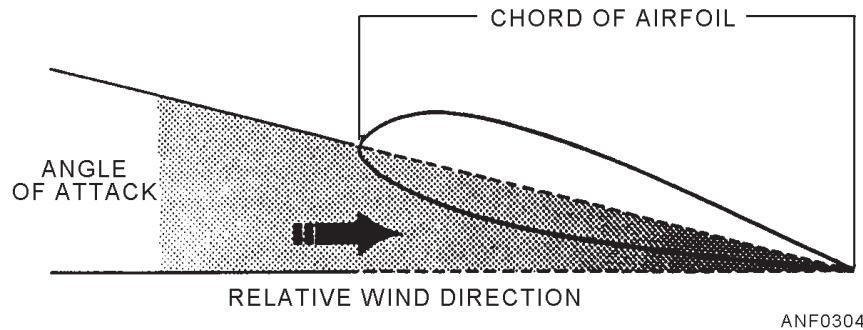


Figure 3-4.—Angle of attack.

upper surface of the airfoil has camber to it, the flow over its surface is disrupted. This disruption causes a wavelike effect to the airflow. The lower surface of the airfoil is relatively flat. The airflow across its surface isn't disrupted. Lift is accomplished by this difference in the airflow across the airfoil.

The shaded area of figure 3-5 shows a low-pressure area on the airfoil's upper surface. This low-pressure area is caused by the air that is disrupted by the camber of the airfoil, and it is the key to lift. There is less pressure on the top surface of the airfoil than there is on the lower surface. The air pressure pushes upward on the lower surface. This difference in pressure causes the airfoil to rise. **Now, you know that lift is developed by the difference between the air pressure on the upper and lower surfaces of the airfoil.** As long as there is less pressure on the upper surface and more pressure on the lower surface of an airfoil, an aircraft has lift. Lift is one of the forces affecting flight.

*Q3-5. What happens when the relative wind strikes the leading edge of an airfoil?*

*Q3-6. Describe how lift is developed.*

### FORCES AFFECTING FLIGHT

**LEARNING OBJECTIVE:** Recognize the four primary forces acting on an aircraft.

An aircraft in flight is in the center of a continuous battle of forces. The conflict of these forces is the key to all maneuvers performed in the air. There is nothing mysterious about these forces—they are definite and known. The direction in which each acts can be calculated. The aircraft is designed to take advantage of each force. These forces are lift, weight, thrust, and drag.

### LIFT

Lift is the force that acts in an upward direction to support the aircraft in the air. It counteracts the effects of weight. Lift must be greater than or equal to weight if flight is to be sustained.

### WEIGHT

Weight is the force of gravity acting downward on the aircraft and everything in the aircraft, such as crew, fuel, and cargo.

### THRUST

Thrust is the force developed by the aircraft's engine. It acts in the forward direction. Thrust must be greater than or equal to the effects of drag for flight to begin or to be sustained.

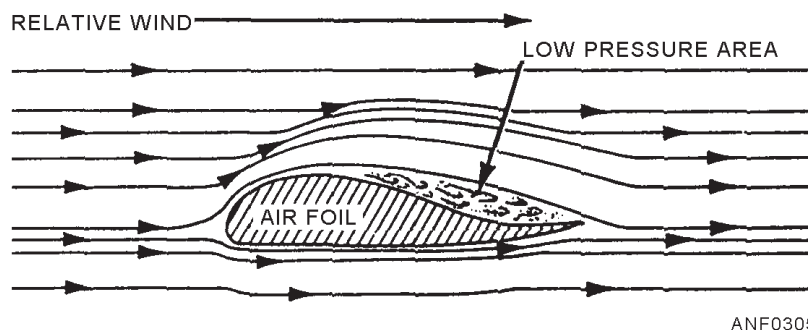


Figure 3-5.—Airflow across an airfoil.

## DRAG

Drag is the force that tends to hold an aircraft back. Drag is caused by the disruption of the airflow about the wings, fuselage (body), and all protruding objects on the aircraft. Drag resists motion as it acts parallel and in the opposite direction in relation to the relative wind. Figure 3-6 shows the direction in which each of these forces acts in relation to an aircraft.

Up to this point, you have learned the physical laws of aerodynamics, airfoils, and the forces affecting flight. To fully understand flight, you must learn about the rotational axes of an aircraft.

*Q3-7. What are the four forces that affect flight?*

## ROTATIONAL AXES

**LEARNING OBJECTIVE:** Identify the three axes of rotation and the terms relative to the aircraft's rotation about these axes.

Any vehicle, such as a ship, a car, or an aircraft, is capable of making three primary movements (roll, pitch, and yaw). The vehicle has three rotational axes that are perpendicular (90 degrees) to each other. These axes are referred to by their direction—longitudinal, lateral, and vertical. Perhaps the most descriptive reference is by what action takes place about a given axis or pivot point—roll, pitch, and yaw.

## LONGITUDINAL AXIS

The longitudinal axis is the pivot point about which an aircraft rolls. The movement associated with roll is best described as the movement of the wing tips (one up and the other down). Figure 3-7 shows this movement. This axis runs fore and aft through the length (nose to tail) of the aircraft. This axis is parallel to the primary direction of the aircraft. The primary direction of a fixed-wing aircraft is always forward. Figure 3-8 shows the longitudinal axis.

## LATERAL AXIS

The lateral axis is the pivot point about which the aircraft pitches. Pitch can best be described as the up and down motion of the nose of the aircraft. Figure 3-7 shows this movement. The pitch axis runs from the left to the right of the aircraft (wing tip to wing tip). It is perpendicular to and intersects the roll axis. Figure 3-8 shows the pitch axis and its relationship to the roll axis.

## VERTICAL AXIS

The vertical axis runs from the top to the bottom of an aircraft. It runs perpendicular to both the roll and pitch axes. The movement associated with this axis is yaw. Yaw is best described as the change in aircraft heading to the right or left of the primary direction of an aircraft. Figure 3-7 shows this movement. Assume you are walking from your work space to an aircraft located 100 feet away. You are trying to walk there in a straight line but are unable to do so because there is a strong wind blowing you off course to your right. This movement to the right is yaw. The yaw axis is shown in figure 3-8.

*Q3-8. Any vehicle (ship, car, or aircraft) is capable of making what three primary movements?*

## FIXED-WING AND ROTARY-WING AIRCRAFT

**LEARNING OBJECTIVE:** Recognize the difference in aerodynamic principles that apply to fixed- and rotary-wing aircraft.

A fixed-wing aircraft depends on forward motion for lift. A rotary-wing aircraft depends on rotating airfoils for lift. The airfoil sections of a fixed-wing aircraft aren't symmetrical. The rotor blades of a helicopter are symmetrical. These differences are important to you if you're to understand aerodynamic principles.

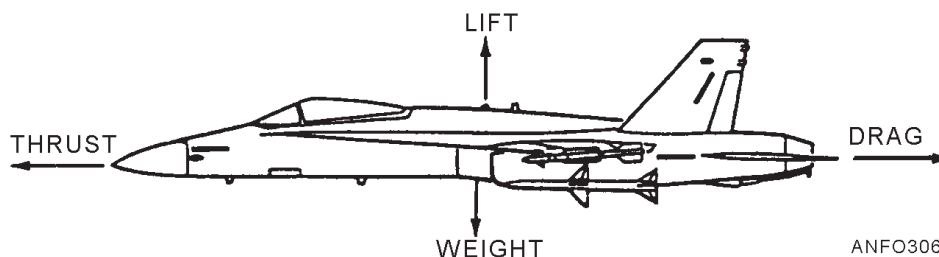
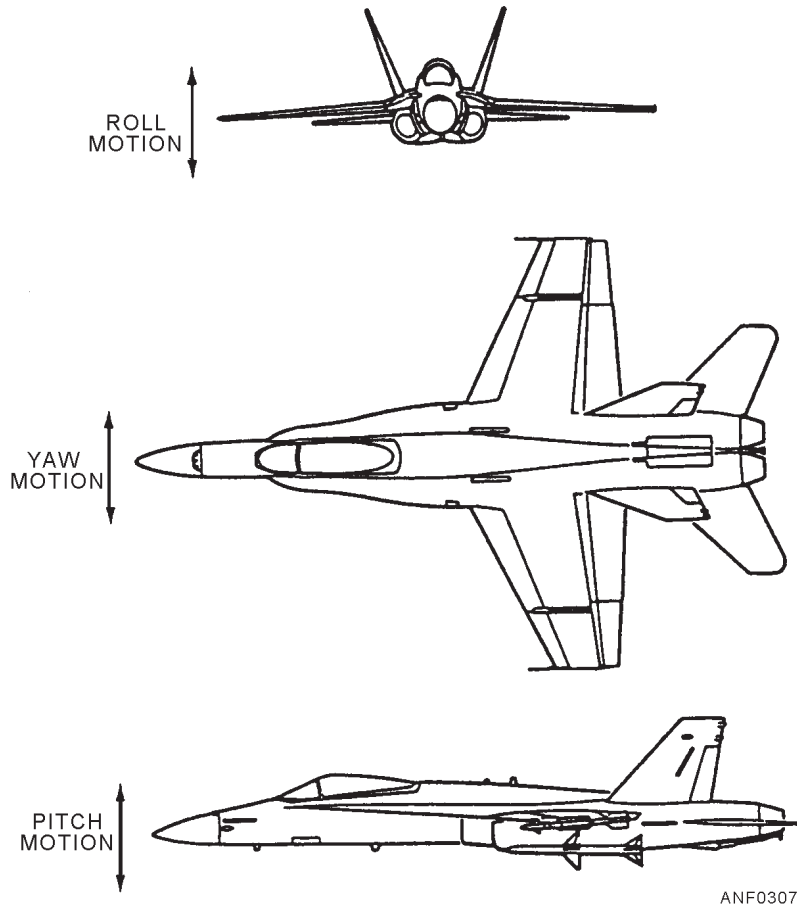
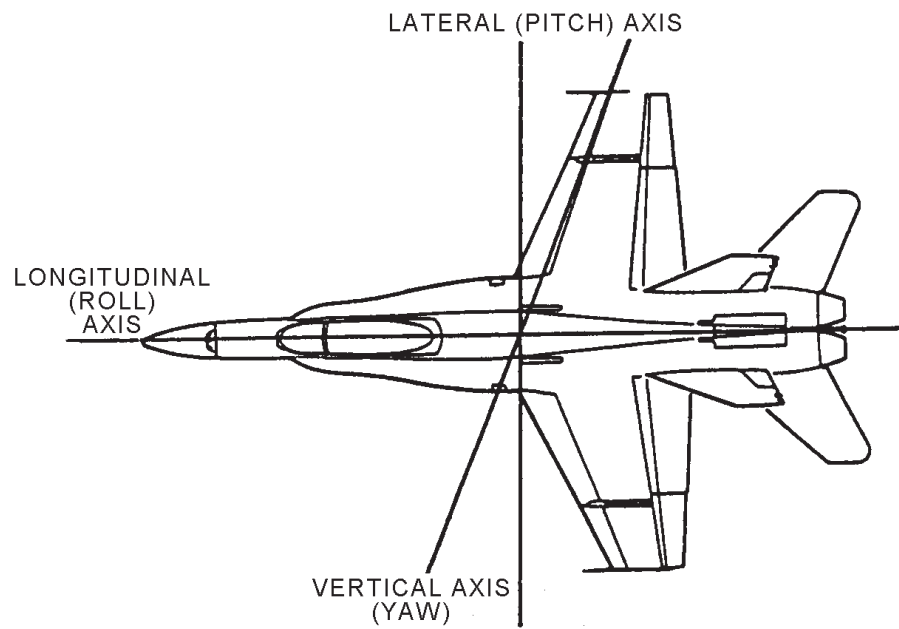


Figure 3-6.—Forces affecting flight.



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Figure 3-7.—Motion about the axes.



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Figure 3-8.—Axes of an aircraft.

## FIXED-WING AIRCRAFT

You have learned about the physical laws and forces that affect flight, the airfoil, and the rotational axes of an aircraft. Now, let's apply these principles to a fixed-wing aircraft in flight. First, motion must exist. Motion is provided by the thrust developed by the engine of the aircraft. This is accomplished by the force exerted by the exhaust gases of a jet aircraft or by the action of the propeller blades on a propeller-driven aircraft. The thrust overcomes the force of inertia and, as the fixed-wing aircraft accelerates, the air flows by the wings. The relative wind striking the leading edge of the wings is split and flows across the upper and lower surfaces. The camber of the upper surface acts as a constriction, which speeds up the airflow and reduces the pressure of the air. The lower surface, being relatively flat, doesn't affect the speed or pressure of the air. There is lower air pressure on the upper surface of the wing than on the lower surface. The fixed-wing aircraft is lifted into the air.

Now that the aircraft is safely in the air, rotational axes come into play. If the nose of the aircraft is raised, the angle of attack changes. Changing the angle of attack causes the aircraft to pivot on its lateral or pitch axis. If you lower the right wing of the aircraft, the left wing rises. The aircraft moves about its longitudinal or roll axis. Assume that the aircraft is in a straight and level flight. There is a strong wind striking the aircraft's nose on the left side, pushing the nose to the right. This causes the tail of the aircraft to move to the left, and the aircraft is pivoting on its vertical or yaw axis. All of these forces are necessary for flight to begin or be sustained.

## ROTARY-WING AIRCRAFT (HELICOPTERS)

The same basic aerodynamic principles you read about earlier in this chapter apply to rotary-wing aircraft. The main difference between fixed-wing and rotary-wing aircraft is the way lift is achieved.

### Lift

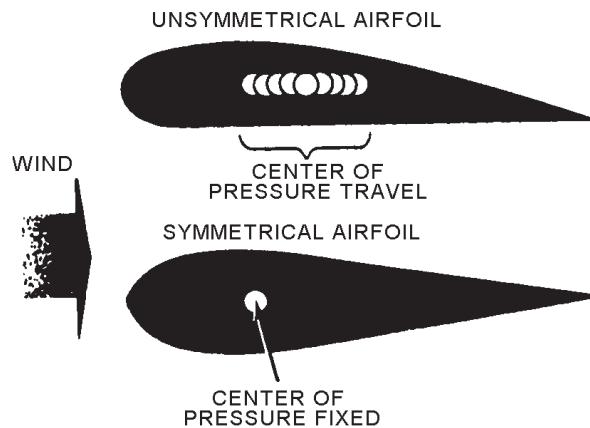
The fixed-wing aircraft gets its lift from a fixed airfoil surface. The helicopter gets lift from rotating airfoils called *rotor blades*. The word *helicopter* comes from the Greek words meaning *helical wing* or *rotating wing*. A helicopter uses two or more engine-driven rotors from which it gets lift and propulsion.

The helicopter's airfoils are the rotor blades. The airfoils of a helicopter are perfectly symmetrical. This means that the upper and lower surfaces are shaped the same. This fact is one of the major differences between the fixed-wing aircraft's airfoil and the helicopter's airfoil. A fixed-wing aircraft's airfoil has a greater camber on the upper surface than on the lower surface. The helicopter's airfoil camber is the same on both surfaces (fig. 3-9). The symmetrical airfoil is used on the helicopter because the center of pressure across its surface is fixed. On the fixed-wing airfoil, the center of pressure moves fore and aft, along the chordline, with changes in the angle of attack (fig. 3-9). If this type of airfoil were used on a rotary-wing aircraft, it would cause the rotor blades to jump around (dive and climb) uncontrollably. With the symmetrical airfoil, this undesirable effect is removed. The airfoil, when rotated, travels smoothly through the air.

The main rotor of a helicopter consists of two or more rotor blades. Lift is accomplished by rotating the blades through the air at a high rate of speed. Lift may be changed by increasing the angle of attack or pitch of the rotor blades. When the rotor is turning and the blades are at zero angle (flat pitch), no lift is developed. This feature provides the pilot with complete control of the lift developed by the rotor blades.

### Directional Control

A pilot controls the direction of flight of the helicopter by tilting the main rotor. If the rotor is tilted forward, the force developed by the rotor is directed downward and aft. Now, apply Newton's third law of motion (action and reaction). Lift will be developed in an upward and forward direction, and the helicopter will tend to rise and move forward. From this example,



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Figure 3-9.—Center of pressure.



you should realize that a pilot can move a helicopter forward or rearward, or to the right or left, simply by tilting the main rotor in the desired direction.

Look at figure 3-10. This points out another major difference between fixed-wing and rotary-wing aircraft. The fixed-wing aircraft can't move up or down or right or left without forward movement. Remember, a fixed-wing aircraft's primary direction is forward. However, a helicopter can move in any direction, with or without forward movement.

### Hovering

Hovering is defined as maintaining a position above a fixed spot on the ground. A helicopter has the ability to remain in one spot in the air with little or no movement in any direction. This is done by equalizing all the forces acting on the helicopters (lift, drag, weight, and thrust). This action also allows a helicopter

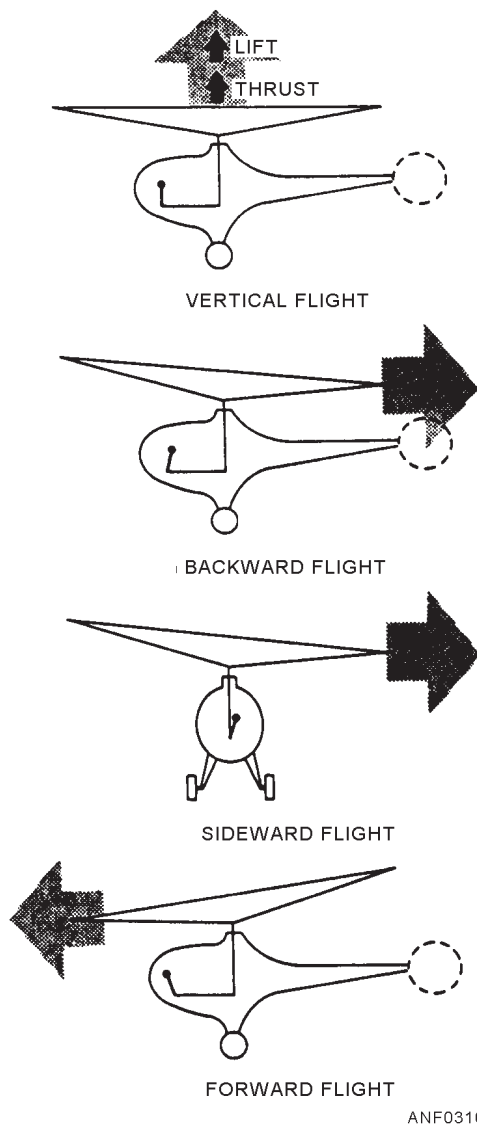


Figure 3-10.—Directional flight attitudes.

to take off or land without a runway. This is another advantage the rotary-wing aircraft has over the fixed-wing aircraft.

### Torque Reaction

As the helicopter's main rotor turns in one direction, the body (fuselage) of the helicopter tends to rotate in the opposite direction (Newton's third law). This is known as *torque reaction*. In a single main rotor helicopter, the usual way of getting rid of torque reaction is by using a tail rotor (anti-torque rotor). This rotor is mounted vertically on the outer portion of the helicopter's tail section. See figure 3-11. The tail rotor produces thrust in the opposite direction of the torque reaction developed by the main rotor. Figure 3-11 shows the manner in which torque reaction is eliminated in a single main rotor helicopter.

- Q3-9. How does the pilot change the angle of attack on (a) an airplane and (b) a helicopter?
- Q3-10. What is the main difference between a helicopter and an airplane?
- Q3-11. What maneuver can a helicopter perform that an airplane cannot?

### SUMMARY

In this chapter, you have been introduced to the principles of flight. You have learned about the principles of flight for fixed-wing and rotary-wing aircraft.

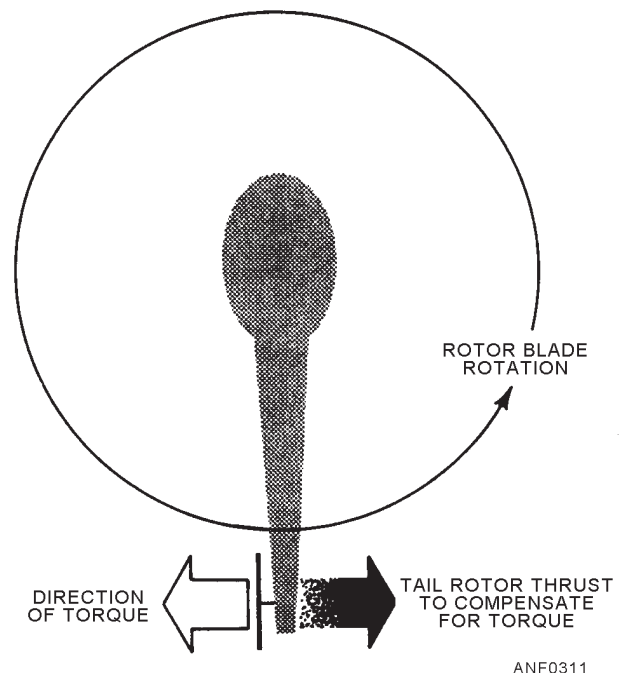


Figure 3-11.—Torque reaction.

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# ASSIGNMENT 3

Textbook Assignment: "Principles of Flight," chapter 3, pages 3-1 through 3-7.

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- 3-1. The study of the forces that enable an aircraft to fly is referred to by what term?
1. Thermodynamics
  2. Aerodynamics
  3. Hydrodynamics
  4. General dynamics
- 3-2. Which of the following is a definition of motion?
1. The act or process of changing place or position
  2. The act or process of achieving inertia
  3. The overcoming of force
  4. The resistance to force
- 3-3. Which of the following terms refers to Newton's first law of motion?
1. Force
  2. Action and reaction
  3. Inertia
  4. Gravity
- 3-4. Thrust must overcome inertia before an aircraft can fly. This is an example of which of the following laws of motion?
1. Newton's first law
  2. Newton's second law
  3. Newton's third law
- 3-5. Newton's law of inertia applies to bodies that are affected in which of the following ways?
1. Those that are at rest only
  2. Those moving in a straight line at a uniform speed only
  3. Those at rest and moving at a uniform speed in a straight line
  4. The willingness of an object to remain at rest or continue in motion
- 3-6. What law of motion is the "force" law?
1. Newton's first law
  2. Newton's second law
  3. Newton's third law
- 3-7. The fact that "for every action there is an equal and opposite reaction" is discussed in which of Newton's laws of motion?
1. First
  2. Second
  3. Third
- IN ANSWERING QUESTIONS 3-8 AND 3-9, REFER TO FIGURE 3-2(B) IN THE TEXT.
- 3-8. At what location is the area of least pressure?
1. To the left of the airfoil
  2. To the right of the airfoil
  3. Beneath the airfoil
  4. Over the airfoil
- 3-9. At what location is the area of increased flow?
1. Over the airfoil
  2. Under the airfoil
  3. To the left of the airfoil
  4. To the right of the airfoil
- 3-10. According to Bernoulli's principle, what happens to the speed and pressure of a fluid flowing through a tube when the fluid reaches a constriction?
1. The speed and pressure of the fluid increases
  2. The speed and pressure of the fluid decreases
  3. The speed decreases and the pressure increases
  4. The speed increases and the pressure decreases
- 3-11. Which of the following components are classified as airfoils?
1. The wings of an aircraft
  2. The rotor blades of a helicopter
  3. The propeller blades of a turboprop aircraft
  4. All of the above
- 3-12. What is the front edge or surface of an airfoil?
1. Chamber
  2. Chord line
  3. Leading edge
  4. Trailing edge

- 3-13. What is an imaginary straight line from the leading edge to the trailing edge of an airfoil?
1. Camber
  2. Chord line
  3. Span
  4. Angle of attack
- 3-14. Which of the following terms identifies the rear edge or surface of the airfoil?
1. Span line
  2. Retreating edge
  3. Chord line
  4. Trailing edge
- 3-15. What is the curve or departure from a straight line from the leading edge to the trailing edge of the airfoil?
1. Camber
  2. Chord line
  3. Angle of attack
  4. The angle of incident
- 3-16. What term is used to describe the direction of the airstream in relation to the airfoil?
1. Angle of attack
  2. Directional heading
  3. Relative wind
  4. Chord line
- 3-17. What is the angle between the chord line and the relative wind called?
1. The angle of attack
  2. The resultant angle
  3. The control angle
  4. The angle of incidence
- 3-18. The generation of lift by an airfoil is dependent upon which of the following factors?
1. The shape of the airfoil's cord
  2. The airfoil being able to create a special airflow in the airstream
  3. The airfoil being able to develop lifting pressure over the airfoil surface
  4. Both 2 and 3 above
- 3-19. As the relative wind strikes the leading edge of an airfoil, the flow of air is split. What part of the airfoil creates the low pressure area on the airfoil's surface?
1. The camber of the airfoil's upper surface
  2. The camber of the airfoil's lower surface
  3. The trailing edge of the airfoil
  4. The leading edge of the airfoil
- 3-20. What speed or pressure causes most of the lift of an airfoil?
1. The speed of the air striking the front of the airfoil
  2. The difference in air pressure on the upper and lower surfaces of the airfoil
  3. The increase in pressure over the airfoil
  4. The decrease in pressure over the airfoil
- 3-21. What is the force that is created by an airfoil?
1. Lift
  2. Drag
  3. Gravity
  4. Thrust
- 3-22. What force overcomes gravity?
1. Drag
  2. Lift
  3. Thrust
  4. Weight
- 3-23. What is the force that holds an aircraft to the ground?
1. Lift
  2. Drag
  3. Gravity
  4. Thrust
- 3-24. What is the force that is created by a propeller, jet engine, or helicopter rotor?
1. Lift
  2. Drag
  3. Gravity
  4. Thrust
- 3-25. What force overcomes drag?
1. Lift
  2. Thrust
  3. Weight
  4. Momentum
- 3-26. What is the force that acts against an aircraft in flight?
1. Lift
  2. Drag
  3. Gravity
  4. Thrust
- 3-27. Aircraft drag acts in what direction in relation to the relative wind?
1. Parallel and in the same direction
  2. Parallel and in the opposite direction
  3. Perpendicular in the same direction
  4. Perpendicular and in the opposite direction

- 3-28. During flight, if the aircraft's lift force and weight force are equal and the thrust force is greater than the drag force, what will happen?
1. The aircraft will lose altitude and lose speed
  2. The aircraft will lose altitude and gain speed
  3. The aircraft will maintain its altitude and lose speed
  4. The aircraft will maintain its altitude and gain speed
- 3-29. Which of the following forces counteracts forward motion of the aircraft?
1. Weight
  2. Lift
  3. Drag
  4. Thrust
- 3-30. What axis is the pivot point about which an aircraft rolls?
1. Longitudinal
  2. Lateral
  3. Vertical
  4. Horizontal
- 3-31. What movement of an aircraft is associated with roll?
1. The up and down movement of the wing tips
  2. The left and right movement of the aircraft's nose
  3. The up and down movement of the aircraft's nose
  4. The fore and aft movement of the wings
- 3-32. What axes runs fore and aft through the length of the aircraft?
1. Longitudinal
  2. Diagonal
  3. Horizontal
  4. Lateral
- 3-33. What axes is the pivot point about which an aircraft pitches?
1. Longitudinal
  2. Lateral
  3. Vertical
  4. Horizontal
- 3-34. What movement of an aircraft is associated with pitch?
1. The up and down movement of the wing tips
  2. The left and right movement of the aircraft's nose
  3. The up and down movement of the aircraft's nose
  4. The fore and aft movement of the wings
- 3-35. What axes runs from the left to the right (wing tip to wing tip) through the width of an aircraft?
1. Pitch
  2. Longitudinal
  3. Vertical
  4. Diagonal
- 3-36. What axes is the pivot point about which an aircraft yaws?
1. Longitudinal
  2. Lateral
  3. Vertical
  4. Horizontal
- 3-37. What axes runs from the top to the bottom of an aircraft?
1. Diagonal
  2. Longitudinal
  3. Lateral
  4. Vertical
- 3-38. What movement of an aircraft is associated with yaw?
1. The up and down movement of the wing tips
  2. The up and down movement of an aircraft's nose
  3. The left and right movement of an aircraft's nose
  4. The fore and aft movement of an aircraft's nose
- 3-39. What force is developed by the engine of an aircraft to provide motion?
1. Lift
  2. Drag
  3. Gravity
  4. Thrust

- 3-40. When an aircraft in flight increases its angle of attack, which of the following actions is accomplished?
1. The aircraft pivots on its longitudinal axis
  2. The aircraft pivots on its lateral axis
  3. The aircraft will turn to the right
  4. The aircraft will turn to the left
- 3-41. When an aircraft in flight encounters a strong gusty, quartering wind on its nose, it tends to drift off course. On what axis does the aircraft pivot when this action occurs?
1. The pitch axis
  2. The yaw axis
  3. The lateral axis
  4. The longitudinal axis
- 3-42. The main difference between fixed-wing aircraft and rotary-wing aircraft is the way in which lift is achieved.
1. True
  2. False
- 3-43. A helicopter uses two or more engine-driven rotors for lift and propulsion.
1. True
  2. False
- 3-44. What is a symmetrical airfoil?
1. An airfoil that has a greater camber on the upper surface than on the lower surface
  2. An airfoil that has less camber on the upper surface than on the lower surface
  3. An airfoil that has a variable center of pressure
  4. An airfoil that has a fixed center of pressure
- 3-45. On an unsymmetrical airfoil, in what direction does the center of pressure move when the angle of attack changes?
1. Forward only
  2. Rearward only
  3. Fore and aft
  4. Inboard and outboard
- 3-46. What does a shifting center of pressure do to a rotor blade?
1. It causes it to move fore and aft uncontrollably
  2. It causes it to move up and down uncontrollably
  3. It causes the pitch of the blades to stabilize
  4. It causes increased lift capabilities
- 3-47. By what means is lift controlled in a helicopter?
1. By increasing and decreasing the engine speed
  2. By increasing and decreasing the rotor speed
  3. By increasing the pitch or angle of attack of the rotor blades
- 3-48. What term is used when a helicopter's main rotor is turning and no lift is being produced by the rotor blades?
1. Angle of attack
  2. Ground idle
  3. Zero thrust
  4. Flat pitch
- 3-49. Directional control of a helicopter is achieved by what means?
1. By tilting the helicopter in the desired direction
  2. By tilting the main rotor in the desired direction
  3. By increasing the pitch of the tail rotor blades
  4. By decreasing the pitch of the tail rotor blades
- 3-50. By what means is hovering achieved in a helicopter?
1. By equalizing lift and drag only
  2. By equalizing lift and thrust only
  3. By equalizing thrust and weight only
  4. By equalizing lift, drag, thrust, and weight
- 3-51. As the helicopter's rotor turns in one direction, the body of the helicopter tends to rotate in the opposite direction. What law or principle explains this action?
1. Newton's third law
  2. Newton's second law
  3. Newton's principle
  4. Bernoulli's principle

3-52. What is the purpose of a tail rotor on a single main rotor helicopter?

1. Recognizing torque
2. Reducing vibration
3. Compensating for thrust
4. Eliminating torque reaction

3-53. In what direction does a tail rotor system produce thrust to compensate for the torque reaction developed by the main rotor?

1. Opposite
2. Same
3. Vertical
4. Radial

